Pest Management Grants Final Report

INTEGRATED WEED MANAGEMENT FOR LETTUCE: OPTIMIZED WEED MANAGEMENT INPUTS MADE ACCORDING TO SEASONAL FLUCTUATIONS IN WEED SEED GERMINATION

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Table of Contents Page

List of Tables Page

Abstract

Herbicide options are limited in vegetables, therefore, our objective is to enhance the value of existing weed control inputs through study of weed biology. To detect shifts in the germination status of several weeds in the soil seedbank, soils at three vegetable fields were sampled periodically from September 1999 until August 2000 and evaluated to determine the

seed fraction that could readily germinate. Weed densities were counted periodically, to detect seasonal emergence patterns. Fifty two to 81% of the annual bluegrass and southern brass buttons, respectively, emerged during winter. Common purslane and hairy nightshade peak emergence occurred in spring and summer with little or no emergence in fall and winter. Whereas, burning nettle, common chickweed, common groundsel, henbit and shepherdspurse emerged continuously without distinct emergence peaks. Seedbank evaluations appear to confirm that seasonal fluctuations in germinability are related to seasonal weed emergence. Evaluations were conducted to determine if weed control in spring and summer-planted lettuce could be maintained with reduced rates of bensulide and pronamide, and/or the brush hoe cultivator. Pronamide plus bensulide at 0.75 plus 3.0 pounds of active ingredient per acre (lb ai/A) provided excellent control of most weeds in summer-planted lettuce and allowed a 13% reduction in pronamide (restricted use, B2 carcinogen) and a 40% reduction in bensulide rate (organophosphate). The brush hoe cultivator in combination with reduced herbicide rates can provide commercially-acceptable weed control. The weed modeling information developed in this project should be implemented through a demonstration project at several locations on the central coast.

Executive summary

Of all pesticides used in minor crops, herbicides are the most difficult to develop and register. Given the current regulatory status of many vegetable herbicides under the Food Quality Protection Act, the tolerances of some vegetable herbicides will likely be cancelled (Bell et al. 2000). Strategies to develop new vegetable herbicides or to produce genetically modified herbicide tolerant crops have severe limitations (Fennimore, 2001). Strategies that seek to preserve existing vegetable herbicides by minimizing the risks associated with their use have a great deal of potential value. One such strategy is to study the biology of weeds to identify characteristics that will allow them to be managed more efficiently with less risk to human safety and the environment.

In the vegetable districts of the central coast of California lettuce is planted from December to August, and the weed spectrum during these long planting intervals varies by season. Approximately 50 and 80% of the annual bluegrass (*Poa annua*) and southern brass buttons (*Cotula australis*), respectively, emerged during winter. In contrast, both common purslane (*Portulaca oleracea*) and hairy nightshade (*Solanum sarrachoides*) had peak emergence in spring and summer with little emergence in fall and winter. On the other hand, burning nettle (*Urtica urens*), common chickweed (*Stellaria media*), common groundsel (*Senecio vulgaris*), henbit (*Lamium amplexicaule*) and shepherdspurse (*Capsella bursa-pastoris*) emerged all year round, thus lacking a distinct peak emergence period. Management of weeds in vegetable crops is accomplished through a combination of herbicides, mechanical tillage and hand hoeing. Because herbicide options are increasingly more limited in vegetable crops, our principal research objective is to enhance the value of existing weed control inputs through greater understanding of weed germination characteristics. Soil samples from three vegetable fields were taken approximately every 45 days during September 1999 to September 2000 to detect shifts in the seed germinability of several weed species in the soil seed bank. These soil samples were placed in greenhouse trays and allowed to germinate for 45 days. At the completion of 45 days the weed seeds were extracted from the soil samples. After extraction the seeds were identified and counted under a microscope. Analysis of germination potential, from samples of annual bluegrass, burning nettle, common chickweed, and shepherdspurse seed extracted from soils in vegetable fields suggest that there is a relationship between seasonal changes in germinability and seasonal weed emergence.

We found that common purslane and hairy nightshade first emerge after 219 hours of 10°C and 452 hours of 4°C have accumulated. In the early season, before sufficient heat units have accumulated to induce common purslane and/or hairy nightshade emergence, weed control inputs can be directed at other weeds such as burning nettle or shepherdspurse that germinate all season. After the critical number of heat units has accumulated, weed control inputs should consider common purslane and hairy nightshade as well. Information from this project should now be tested in commercial fields to determine if knowledge of the expected weed population can be used to improve herbicide use efficiency.

During the course of this research we have found an extremely effective cultivator, the brush hoe, that may allow some herbicide inputs to be replaced by mechanical, i.e., non-chemical, weed control inputs.

Introduction

Herbicide options are limited for California lettuce producers. Currently there are no postemergence herbicides registered for broadleaf weed control in lettuce, forcing growers to rely on preemergence herbicides. Decisions about preemergence herbicide choice and rate are made prior to weed emergence and based entirely on field history rather than predicted or observed weed pressure. Lettuce in the Salinas Valley is planted from late December until August and during this time there are seasonal fluctuations in weed density and composition. The hypothesis tested was that a cycle of seasonal germinability exists in many of the common weed species of coastal California that is regulated by seasonal changes in air and soil temperatures. It may be possible to take advantage of this seasonal cycle in order to manage weeds with more precise weed control inputs, such as reduced herbicide inputs or a combination of reduced herbicide inputs and nonchemical inputs. There are currently no decision support tools available for weed management in coastal California lettuce. Knowledge of potential weed emergence from the seed bank would provide growers with more information on which to base weed management decisions. New cultivator designs such as the brush hoe cultivator have shown potential for use in vegetables (Colquhoin et al. 1999). Growers may decide to reduce or eliminate herbicide applications in lettuce if light weed populations can be reliably predicted and managed with improved mechanical cultivators.

Present objectives are to: 1) Develop an emergence model based on air and soil temperatures for common central coast weeds such as: burning nettle, common purslane, hairy nightshade and shepherdspurse, and 2) Develop a weed management program for lettuce based on reduced herbicide rates and improved cultivator designs.

Materials and methods

Objective 1. Three studies were established in Monterey County, CA, one on the Bengard farm near Chualar was initiated March 1998, and the second at the USDA/ARS Station near Salinas, CA was initiated April 1998 and the third site at the Spence farm 6 miles S. of Salinas was initiated April 1998. The Chualar study was seeded to lettuce in April 2000 and broccoli in July 2000, spinach was planted into the Spence study in April 2000 followed by broccoli in June 2000 and cereal rye in October 2000 and the Salinas study was seeded to lettuce April 2000 followed by snap beans in July 2000 and broccoli in October 2000. At each study site, there are four plots with five fixed quadrats of 0.1 m^2 each laid out in a W-shaped pattern (Forcella et al. 1992). Four soil cores (5 cm wide by 7 cm deep) are taken from each quadrat, totaling 2,749 cm^3 per plot. The 20 cores are bulked by plot, placed in 26 X 26 cm trays, incubated in a growth chamber using temperatures and photoperiods listed in Table 1. At intervals of 14 to16 days, weeds that emerge from the trays are identified, counted, and removed, the soil is then stirred. At the end of a 45 to 46 day period the remaining ungerminated seeds are extracted from the soil by washing through a 60-mesh screen (opening area of 0.048 mm^2). After air-drying, the elutriated samples are sieved through a 12 mesh screen (opening area of 4.75 mm^2) to get rid of the large mineral particles and then undergo a floatation procedure described by Ball and Miller (1989). The floating fraction is collected and inspected, under a 20X dissection microscope, with regards to species and viability. Seed viability is determined by the pressure test as described in Forcella et al. (1992). Seeds that germinate during the growth chamber incubation period are considered germinable, i.e., have a high germination potential. The percentage of germinable seeds in the seed bank, by species, are being calculated using the equation $G = S / (S + U)$ where G is the germinable proportion, S is the number of seedlings that emerged in the growth chamber and U is the number of ungerminated viable seeds extracted from the soil. All field plots are sampled at least every 45 to 46 days throughout the year to detect seasonal changes in the percentage of germinable seeds. Soil temperatures are being monitored at the Hartnell and Spence sites throughout the study period. Field weed densities are counted and the weeds are removed periodically at the same fixed quadrats in each plot.

Degree-day models for the emergence of common purslane and hairy nightshade were calculated using the procedure described in Wilen et al. (1996). Degree-days were determined using the 'calculate degree days' option and the 'single sine' method available on the University of California, Davis IPM website[1]. Temperature thresholds for common purslane of 10°C and hairy nightshade of 4°C were based on the results published in Zimmerman (1977), and Roberts and Broddell (1983). In our research we have determined that the lower temperature threshold for burning nettle was 6°C (Fennimore and Li unpublished results). The biofix date (start date) was set at January 8, 2000, when the coldest air temperature occurred in the winter of 1999-00.

Objective 2. Three studies comparing the weed control efficacy of a brush hoe cultivator with a standard cultivator were initiated in the spring and summer of 2000 (Table 2). All cultural practices were typical for the Salinas valley including hoeing, thinning and cultivation. Lettuce was cultivated at the 4-leaf stage. Weed density counts were taken before and after each cultivation to evaluate the efficacy of the cultivators. Crop stand counts were taken before lettuce thinning, and the time to thin lettuce to commercial stand densities, as well as the time to hand weed the lettuce, was determined by timing a hoe hand as he thinned or weeded each plot. Mean separation was performed using Fisher's Protected LSD.

Results

Field emergence. Southern brass buttons and annual bluegrass emerged mostly in the fall and winter (Table 3). Summer annuals, common purslane and hairy nightshade emerged in

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[1] Available online at http://www.ipm.ucdavis.edu

the spring and summer. Burning nettle, common chickweed, common groundsel, henbit and shepherdspurse emerged throughout the year. Common purslane emerged 117 days after the biofix date, January 8, 2000, when 392 hours of 10°C heat units had accumulated and hairy nightshade emerged 26 days after the biofix date when 217 hours of 4°C heat units had accumulated. Burning nettle emerged 26 days after the biofix date when 164 hours of 6°C heat units had accumulated. Given the mild year-round temperatures in the Salinas Valley, and the fact that some fraction of the burning nettle seedbank is always germinable, means that burning nettle can emerge all year.

Results of soil seedbank germinability assays indicate that annual bluegrass and southern brass buttons have the greatest potential to germinate in the fall and winter months (Table 4). Common purslane is capable of germinating only in the warm summer months, while hairy nightshade has the potential to germinate in all seasons except winter. Common chickweed germinability was low in early and late spring, but even then 2 to 3% of the seedbank was germinable. Burning nettle, common groundsel, henbit and shepherdspurse seed had the potential to germinate all year.

Comparisons of the brush hoe cultivator with a standard cultivator. In the spring evaluation at Hartnell Farm, the brush hoe provided better hairy nightshade control in all herbicide treatments except bensulide at 5.0 lb/A (Table 5). A comparison of the weed control efficacy of the two cultivators, within herbicide treatments in the summer evaluation at Spence Farm, revealed that pronamide at 0.75 and 1.2 lb ai/A, bensulide at 3.0 and no herbicide (untreated check) resulted in significantly greater weed control (nettleleaf goosefoot, redroot pigweed and shepherdspurse) where the brush hoe was used versus the standard cultivator (Table 6). At Spence Farm, hand-weeding times were significantly lower in all brush hoe cultivated treatments compared to plots cultivated with a standard cultivator regardless of herbicide (Table 7). The brush hoe had no significant effect on lettuce stand or yield compared to the standard cultivator at Spence Farm (data not shown). In the second summer evaluation conducted in cooperation with American Farms, the brush hoe provided numerically better shepherdspurse control than the grower's cultivator regardless of herbicide treatment, though these differences were not significant (Table 8). Similarly, results at American Farms revealed that thinning times in the brush hoe cultivated plots were slightly less than in those plots cultivated with the standard cultivator (Table 9).

Discussion

Field emergence and seasonally adjusted weed control inputs. Weed populations changed by season at all sites. The pattern of weed emergence suggests that weed control inputs should vary by season and that a seasonally adjusted weed control program may provide equal or better weed control with reduced herbicide inputs. For example a winter weed control program for lettuce might be 0.75 to 0.95 lb ai/A pronamide in combination with the brush hoe cultivator. The use of bensulide in the winter would be unproductive since this herbicide is not active on most of the species, such as common chickweed and shepherdspurse, present at that time. A summer lettuce weed control program based on pronamide plus bensulide at 0.75 + 3.0 in combination with the brush hoe would combine the strengths of both herbicides with the brush hoe to provide control of most weeds emerging at that time.

Growers and PCA's are very interested in seasonally adjusted weed control programs. Results of this work will contribute to seasonally-adjusted common purslane recommendations for lettuce. Adoption of the brush hoe cultivator may be limited by the slow speed of operation.

Outreach. Monterey County Farm Advisor Richard Smith and the PI hosted a field day on 7.26.00, and some of the work described above was presented to about 30 pest control advisors, farmers and Cooperative Extension personnel. Presentation of these results has been made at the Central Coast CAPCA meeting 6.8.00, at the PAPA meeting 9.6.00, the California Celery Research Advisory Board meeting 9.20.00, the Salinas Valley Weed School on 11.29.00, the California Weed Science Society Meeting 1.9.01 and the Weed Science Society of America 2.12.01. In the past 11 months the results of this study have been presented to over 300 growers, consultants, and scientists. Acknowledgment of the California Department of Regulation was given in all presentations. A photo set of the brush hoe has been taken. These photos are being used in extension education seminars, extension publications and at professional meetings.

Summary and conclusions

The objectives of this project are: 1) Develop an emergence model based on air and soil temperatures for common central coast weeds such as: burning nettle, common purslane, hairy nightshade, redroot pigweed and shepherdspurse, and 2) Develop a weed management program for lettuce based on reduced herbicide rates and improved cultivator designs. We have conducted three full seasons of research on this project and feel that we have accomplished the following:

- We have developed an emergence model for burning nettle, common purslane and hairy nightshade based on degree-day accumulation.

- This project has demonstrated seasonal variation in weed emergence and germination potential. The significance of this finding is that weed management inputs in lettuce should vary by season. For example, we plan to recommend that bensulide not be used during December to February since weeds that it controls do not emerge during that time. This recommendation will help eliminate unnecessary expense to growers by minimizing the use of needless herbicide applications and also will minimize unnecessary applicator exposure.

- The brush hoe cultivator will allow cultivation very close to the lettuce seed line, thus uprooting most weeds. This implement may allow the use of reduced herbicide inputs without exposing the growers to high levels of economic risk.

- The findings of this research must be refined into specific grower recommendations for on-farm use. A demonstration program should be conducted to integrate the weed emergence model developed here into a vegetable weed management system.

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List of publications produced

Li, X., S.A. Fennimore. 2001. Seasonal variation in germinability and light sensitivity of common purslane (*Portulaca oleracea*) seeds. Weed Science Society of America Abstracts, 41:50.

Fennimore, S.A. 2001. Future weed management options for vegetable producers. Weed Science Society of America Abstracts, 41:140.

Fennimore, S.A. and X. Li. 2001. Seasonal Fluctuations In Weed Emergence On The Central Coast. Proceedings of the California Weed Science Society. In press.

Appendix. Tables

Table 1. Temperature[1] and light conditions in the growth chamber vary by half-season.

Start date	End date (days [2])	Photoperiod [3]	Temperature (°C) Day	Temperature (°C) Night
21-Sep-99	05-Nov-99 (45)	7:00-18:30	25	6
06-Nov-99	20-Dec-99 (45)	7:00-17:00	20	5
21-Dec-99	03-Feb-00 (45)	7:00-17:00	20	-1
04-Feb-00	20-Mar-00 (46)	6:30-18:00	20	2
21-Mar-00	5-May-00 (46)	6:30-20:00	25	3
6-May-00	20-Jun-00 (46)	6:00-20:00	25	9
21-Jun-00	5-Aug-00 (46)	6:00-20:00	28	14
5-Aug-00	20-Sep-00 (46)	6:30-19:30	28	14

[1] 5 cm soil temperatures at Salinas, CA, since 21 September 1999.

[2] Days elapsed

[3] Day-length of the median date of the period covered (i.e., 14 Oct., 29 Nov., 14 Jan., 28 Feb., 14 Apr., 29 May, 14 Jul., 29 Aug., respectively.

Table 2. Grower cooperators, planting dates and cultivation dates of brush hoe evaluations.

Grower	Plant date	Cultivation date
Hartnell Farm	April 12, 2000	May 15, 2000
D. Tamagni/Spence Farm	May 30, 2000	June 22, 2000
Israel Morales/American Farms	June 28, 2000	July 17, 2000

Table 3. Field emergence percentage by season of winter annuals (annual bluegrass and southern brass buttons), summer annuals (common purslane and hairy nightshade), and continuously germinating species (burning nettle, common chickweed, common groundsel, henbit, and shepherdspurse) in the Salinas valley. The percentage total sums to 100% for the 12-month period from 21 September 1999 to 20 September 2000.

		Seasonal percentage contribution			
	Sites	Fall	Winter	Spring	Summer
S. Brass buttons	Spence	12	81	0	7
Bluegrass	Salinas	32	52	1	15
H. Nightshade	Spence	4	0	46	50
Purslane	Spence	0	0	35	65
Chickweed	Salinas	25	39	14	22
Chickweed	Spence	15	62	9	14
Groundsel	Salinas	13	20	37	30
Groundsel	Spence	11	19	31	39
Henbit	Spence	13	25	21	41
B. Nettle	Salinas	13	35	27	25
Shepherdspurse	Salinas	17	28	29	26
Shepherdspurse	Spence	14	36	34	16

Table 4. Germinability of seeds from the soil reserves of weed species common in the Salinas valley vegetable fields.

Species	Germinable seed (%) by half season (mean$\pm$SE)							
	21Sep-5Nov99	6Nov-20Dec99	21Dec99-3Feb00	4Feb-20Mar00	21Mar-6May00	6May-20June00	21June-5Aug00	6Aug-20Sep00
Ann. bluegrass	51 ± 5^{a}	55 ± 6^{a}	30 ± 1^{b}	3 ± 1^{d}	0 ± 0^{e}	1 ± 1^{de}	3 ± 1^{d}	20 ± 3^{c}
C. chickweed	29 ± 4^{b}	18 ± 6^{c}	19 ± 1^{c}	20 ± 3^{bc}	2 ± 1^{d}	3 ± 1^{d}	14 ± 2^{c}	43 ± 6^{a}
C. groundsel	18 ± 9^{c}	29 ± 3^{bc}	32 ± 11^{bc}	55 ± 19^{ab}	37 ± 13^{abc}	39 ± 7^{abc}	74 ± 9^{a}	63 ± 15^{ab}
C. purslane	3 ± 1	0 ± 0	0 ± 0	0 ± 0	12 ± 8	18 ± 18	18 ± 5	26 ± 2
H. nightshade	80 ± 13^{ab}	68 ± 19^{b}	8 ± 3^{c}	25 ± 9^{c}	87 ± 8^{ab}	100 ± 0^{a}	100 ± 0^{a}	100 ± 0^{a}
Henbit	43 ± 19^{ab}	58 ± 17^{a}	53 ± 7^{ab}	40 ± 16^{ab}	14 ± 5^{b}	47 ± 9^{ab}	30 ± 11^{ab}	52 ± 16^{a}
Nettle	46 ± 7^{ab}	39 ± 4^{abc}	31 ± 2^{bc}	33 ± 5^{bc}	11 ± 4^{d}	13 ± 4^{d}	29 ± 8^{c}	52 ± 2^{a}
Shepherdspurse	36 ± 3^{ab}	57 ± 14^{ab}	60 ± 14^{a}	43 ± 6^{ab}	25 ± 2^{b}	54 ± 17^{ab}	28 ± 3^{ab}	43 ± 11^{ab}
S. brassbuttons	56 ± 8^{bc}	56 ± 16^{bc}	92 ± 8^{a}	34 ± 23^{cd}	0 ± 0^{e}	0 ± 0^{e}	5 ± 2^{de}	78 ± 22^{ab}

Within a row, data with the same superscript letter(s) are not significantly different from one another at P = 0.05, based on least significant difference tests.

Table 5. Differences in hairy nightshade control resulting from the brush hoe and the standard cultivator in combination with pronamide and bensulide treatments in a spring trial at Hartnell Farm. The percent weed control was calculated using the equation [(B-A)/B]100 where B = the number of weeds per 2,652 cm^2 before cultivation, and A = the number of weeds per 2,652 cm^2 after cultivation. The before and after counts were both taken at the same location within each plot.

		Percent control		
Herbicide	Rate lb ai/A	Brush hoe	Standard	Difference
pronamide	0.75	95	63	32 *
pronamide	1.2	89	70	19 *
bensulide	3.0	66	50	16 *
bensulide	5.0	63	52	11
pronamide + bensulide	0.75 + 3.0	83	58	25 *
untreated check	--	67	55	12 *
LSD 0.05				12

* Significantly different at P = 0.05 for comparisons across cultivators but within an herbicide rate.

Table 6. Differences in nettleleaf goosefoot, redroot pigweed and shepherdspurse control resulting from the brush hoe and the standard cultivator in combination with pronamide and bensulide treatments in a summer trial at Spence Farm. The percent weed control was calculated as shown in Table 5. The before and after counts were both taken at the same location within each plot.

		Percent control		
Herbicide	Rate lb ai/A	Brush hoe	Standard	Difference
pronamide	0.75	70.3	41.3	29.0 *
pronamide	1.2	73.3	50.6	22.7 *
bensulide	3.0	80.6	68.1	12.5 *
bensulide	5.0	79.3	69.1	10.2
pronamide + bensulide	0.75 + 3.0	86.1	76.1	10.0
untreated check	--	65.6	46.8	18.8 *
LSD 0.05				12.4

* Significantly different at P = 0.05 for comparisons across cultivators but within an herbicide rate.

Table 7. Differences in hand weeding time in hours per acre resulting from the brush hoe and the standard cultivation treatments used in combination with pronamide and bensulide treatments in a summer trial at Spence Farm.

		Hand weeding time (hr./ A)		
Herbicide	Rate lb ai/A	Brush hoe	Standard	Difference
pronamide	0.75	6	50	-44 *
pronamide	1.2	7	42	-35 *
bensulide	3.0	6	31	-25 *
bensulide	5.0	6	34	-28 *
pronamide + bensulide	0.75 + 3.0	5	26	-21 *
untreated check	--	9	40	-31 *
LSD 0.05				14

* Significantly different at P = 0.05 for comparisons across cultivators but within an herbicide rate.

Table 8. Differences in shepherdspurse control resulting from the brush hoe and the standard cultivator in combination with pronamide and bensulide treatments in a summer trial at American Farms. The percent weed control was calculated as shown in Table 5. The before and after counts were both taken at the same location within each plot.

		Percent control		
Herbicide	Rate lb ai/A	Brush hoe	Standard	Difference
pronamide	1.5	79.6	62.2	17.4
bensulide	3.0	77.8	43.4	34.4
pronamide + bensulide	1.5 + 3.0	82.4	40.0	42.4
untreated check	--	82.9	47.5	35.4
LSD 0.05				ns

Table 9. Differences in hand weeding time in hours per acre resulting from the brush hoe and the standard cultivation treatments used in combination with pronamide and bensulide treatments in a summer trial at American Farms.

		Hand weeding time (hr./ A)		
Herbicide	Rate lb ai/A	Brush hoe	Standard	Difference
pronamide	1.5	4.9	5.1	-0.2
bensulide	3.0	5.3	5.5	-0.2
pronamide + bensulide	1.5 + 3.0	5.3	6.0	-0.7
untreated check	--	4.8	5.7	-0.9
LSD 0.05				ns